(Published in The Washington Post, June 3, 1990, page D3)

BRINGING RADIO UP TO DATE: NEW DIGITAL TECHNOLOGY CAN SOUND AS CLEAR AS COMPACT DISCS

By Steve Crowley

COMPACT DISCS sound great. Outselling records since 1987, they offer the finest in recorded audio quality. They're also a hit at radio stations, where they require much less maintenance hassle than tapes or records. But turn your dial to even the strongest station and something's missing: The brightness and definition don't come across on the air. And while you're driving or jogging, the best receivers can be interrupted by noise or distortion.

The problem is that both AM and FM radio are now comparatively low-tech methods of broadcasting. They've served us well for decades, but can't match compact-disc digital quality due to inherent limitations in their analog transmission schemes.

In Europe, they've started from scratch and combined the latest in signal processing hardware with research on the psychology of hearing to develop a new type of digital radio that offers the sound quality of compact discs. Canada is already testing the new technology. And some day it might allow U.S. broadcasters to get highest-caliber audio to the listener.

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The Trouble Is in Your Set

There are a number of reasons why conventional radio can't match the quality of CD sound. Compact-disc audio covers the frequency range of 20 to 20,000 Hz (hertz, or cycles per second) covering the lowest rumblings of thunder to the highest overtones of a violin. That's about the range of human hearing as well. FM's frequency response, though, is cut off at 15,000 Hz.

FM also suffers from "multi-path" interference. This can occur in built-up areas like downtown Washington where the transmitting antenna doesn't have a line-of-sight path to the receiver. This means that your car tuner, for example, is picking up radio waves that have been diffracted or reflected off buildings on the way to your antenna. Like ripples meeting in a pond, the multiple waves can reinforce or cancel each other at different points. This is most obvious in an automobile when pulling up to a stop light; your favorite station sometimes fizzles to nothing. Move a few feet forward, and it's all right -- you've changed the geometry of the multi-path problem.

AM radio has even lower audio response: Transmitted frequency response is limited to 10,000 Hz and receiver response is worse. AM also doesn't have FM's "capture effect" that lets FM lock on to one signal to the exclusion of others. Not only are other AM stations sometimes picked up, but also electrical noise from sources such as personal computers, lightning and power lines. The Federal Communications Commission (FCC) is taking steps to reduce AM interference by tightening technical standards, by encouraging interference reduction efforts between stations and by proposing that some increase power to overcome noise better. In concert, some receiver manufacturers are planning to improve receiver frequency response; they've been reluctant to do so in the past partly because that meant making interference more noticeable. These measures will improve the quality of AM in coming years, but it will never match FM.

Both FM and AM are "analog" transmission methods. That is, the information they carry (such as the fluctuating tones of music or voice) causes a continuous range of variation in the frequency (FM) or amplitude (AM) of the carrier wave {see illustration} . But sound can also be encoded as a series of binary (0/1, on/off) digits, with the sequence corresponding to a certain pitch, volume, etc. As in a CD recording, it is more accurate and noise-free than analog modes.

Over-the-air digital audio transmission has been tried before. The problem with previous schemes is that they require so much of the radio spectrum that they aren't practical for general use. Space in the range of frequencies designated for radio is extremely limited; it is divided into sections for different types of transmissions (AM, FM, short wave, TV), and further subdivided into allotted frequencies for individual stations. A single station's channel can only accommodate so much data. Any more, and it bleeds over its assigned boundaries and causes interference to communications services on adjacent frequencies. Sending all the information in a CD through the air thus requires a block of spectrum several times that used by an FM station, and that kind of space simply isn't available.

Two consortia of European broadcasting agencies and consumer electronics companies -- the European Broadcasting Union and the Eureka 147 Digital Audio Broadcasting Project -- have spent four years and $48 million to create a new, practical digital audio broadcasting system that eliminates the foibles of AM and FM. Commonly known as the Eureka system, it can deliver CD-quality sound to the listener without hogging huge amounts of the radio spectrum.

The Eureka system achieves this, in part, by throwing much of the audio information away. That doesn't sound like a very good way to accurately reproduce audio; and it's not. Indeed, Eureka can't physically duplicate the full audio output of, say, a violin. Instead, it reproduces the way it sounds to people -- which is quite a different thing.

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The World of Invisible Sound

"I couldn't hear the phone. I was in the shower." Sounds are concealed by others all the time. A TV can't be heard over a vacuum cleaner. Similarly, a piece of music drowns out parts of itself. Louder notes mask softer ones. We don't hear a lot of what's going on.

The property of masking is well known to psychologists who study human responses to sound, or psychoacoustics. While engineers measure a sound's frequency and intensity, psychologists are concerned with their perception as pitch and loudness. In masking, the closer two tones are in frequency, the greater the likelihood that the louder will mask the softer. Increasing the frequency separation makes the softer tone more apparent. Masking plays an important role in clinical audiology: When a loud test tone is generated to test an impaired ear, the other ear may detect it and bias the results. This is overcome by introducing a masking noise in the non-test ear that makes the test tone imperceptible.

The Eureka system uses masking to eliminate the details of audio that can't be heard. First, the audio at the radio studio is converted to digital data. Then, the data are analyzed to determine which loud sounds are masking which softer sounds, based on a model of human psychoacoustic characteristics. The loud sounds are kept and the softer ones that can't be heard are discarded. Additionally, the amount of data representing louder sounds is reduced; this increases noise in the audio, but not enough to rise above the threshold of perception.

To further reduce the size of the transmission, the data rate is varied according to the amount of activity in the audio. Rock music requires more information than chamber music, which requires more information than an announcer. The transmission system is designed for the highest data rate required. During slow points in the audio, non-audio data can be transmitted increasing the utility of the receiver {see box} . Taken together, all these techniques allow the amount of audio data to be reduced by more than 80 percent with no perceptible degradation.

This analysis and restructuring of audio in real-time takes a lot of computing power, but the increasing economies of digital signal processing (DSP) are making it practical for consumer use. DSP has been used for years in areas where complex signals need to be analyzed and processed, such as biomedical engineering, seismic analysis and speech recognition. DSP of the scope required by the Eureka system used to require prohibitively large computers. Today, the necessary DSP devices are available on integrated circuits. They're similar to microprocessors, but are optimized for signal processing calculations.

The audio-reduction scheme is not foolproof. Listener adjustment of receiver tone controls can disturb the critical loudness relationship between masking and masked frequencies. Noise might be unmasked. Also, in the unlikely event that one of these stations was recorded and played back on another station, the audio would be reduced a second time. Noise that was originally just below the threshold of hearing could cascade and become perceptible. To help prevent these impairments, a mask-to-noise margin is built in; the system doesn't reduce audio to the absolute minimum. These concerns may limit application of this technology in other consumer electronics.

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Interference Calls

Reducing the amount of data needed to represent audio helps lower spectrum requirements -- but that still leaves the multi-path interference problem. A radio signal carrying precise digital data can still be wiped out at certain locations. The Eureka system solves multi-path problems by taking advantage of the way waves reinforce or neutralize each other depending on whether they are in or out of phase. Since the patterns of interference at a given location depend on the frequency of the signal, multi-path interference will usually occur on one frequency at a time.

With the Eureka system, the data are split up and portions transmitted on many closely-spaced frequencies. Since only one frequency will be out of service at any one time, most of the frequencies, and hence most of the data, will be available.

But even the missing information can be simulated by using error-correction techniques. Extra data representing error-correction information are added to the audio data stream. These data tell the receiver what patterns of audio data it should be receiving at any instant. If the receiver detects a missing element, it then uses the error-correction information to accurately predict what the missing or incorrect data should have been and add them in.

Another performance enhancement can be achieved by "interleaving" the audio data in time. A cluster of data representing a millisecond of audio can be broken up, spread out and transmitted over several seconds; the parts can then be recombined by the receiver. Thus if all frequencies are lost for a split second -- perhaps when driving under a bridge -- there doesn't have to be a total loss of audio as with AM or FM; instead, there could be a less noticeable degradation over several seconds.

These error-correction features enable the system to use much less power than conventional radio stations. With AM and FM, high power is needed to get a usable signal to most locations most of the time. Instead of brute force, the Eureka system uses the mathematics of error correction to finesse the audio data to the receiver. A typical FM station in Washington transmits 50,000 watts. The Eureka system would probably need less than 2,500 watts for equivalent coverage.

In recent tests, the city of Rennes, France (pop. 200,000) and the surrounding countryside were served with an on-the-air experimental system with a power of 11 watts. This reduced power requirement is a big benefit to stations; it means lower transmitter operating costs and (in the United States) easier compliance with the FCC's guidelines for human exposure to radio-frequency energy. It also reduces the prospect of interference to other services.

Eureka's final technical configuration is uncertain. The developers are seeking frequencies for use in Europe, where the audio may be transmitted by satellite. This would be augmented with ground-based transmitters to fill in gaps and provide local coverage.

Because of the local nature of broadcasting in this country, a digital audio broadcasting system here would probably be used by existing AM and FM stations as a complement to their existing service. Much as television stations will be using a second channel to simultaneously broadcast high-definition television, radio stations would send "high-definition" audio on a separate frequency. Since the Eureka system is incompatible with existing radios, receiver cost will have a big impact on the extent to which the new service is used by the public. Today, Eureka receivers have an estimated cost of several hundred dollars. As with all electronics, the price would probably drop rapidly with increased production.

It's uncertain where the needed spectrum would come from for a digital audio broadcasting service in the United States New radio technologies are hard to introduce in this country because we already use most of the radio-frequency spectrum. A mitigating factor is that the Eureka system is electronically "friendly" because of its low power. This reduces the chance of interference to other communications systems. Likewise, its error-correction feature means it is highly resistant to interference from other radio transmitters. These factors may enable spectrum-sharing with existing services. Another plus is the Eureka system's spectrum efficiency. From one location, three separate stereo audio programs, or "stations," can be sent in the same amount of spectrum required by one FM station.

Since all stations can emanate from one location with equal quality, the system could be technically democratizing. Every station in a city could have equal-quality digital signals -- a boon to stations having coverage problems, a bust to those now enjoying a technical advantage.

That's not as big a concern in Canada, where nearly half the radio stations are public broadcasters subsidized by the government -- and where the Eureka system is now being tested. Under consideration is a plan to introduce the system between 1995 and 2000, with existing AM and FM stations getting priority. A satellite service would be provided to provide national programming for all areas, including remote rural locations. Canada also has a plan to deal with the technical problems of AM and FM: If the Eureka system were to become established, they'd just be turned off.

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Don't Touch That Dial! *(sidebar)*

STANDARD radio broadcast signals convey voice or music by imbedding it in a carrier wave. When that mixed signal arrives at your receiver, the desired carrier frequency is selected by the tuner circuits.

The high-frequency carrier is filtered out, leaving only the relatively slow-changing audio signals, which are then amplified and sent to the speakers.

With the Eureka system, radios are essentially small computers that convert the received digital audio data to analog form. They can also be "smart" radios that give the listener unprecedented options. Stations could transmit a code corresponding to their type of format, or the coded name of the song being played or the name of a particular program. Instead of having to tune across the dial to find a program, the receiver could be instructed to find an Orioles game, the next available traffic report or those stations best matching an individual's taste in music. Data might also be used to display weather warnings, station slogans, contest phone numbers or still pictures.

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